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LASER ANNEALING OF 5.56MM AND 20MM CARTRIDGE CASES.(U)
APR 77 K A GREEN, R W WICK, C STEINKE
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LASER ANNEALING OF 5.56MM AND 20MM CARTRIDGE CASES

April 1977

FRANKFORD ARSENAL
U.S. ARMY
ARMAMENT COMMAND
PHILADELPHIA, PENNSYLVANIA 19137

Pitman-Dunn Laboratory

U.S. ARMY ARMAMENT COMMAND
FRANKFORD ARSENAL
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The feasibility of using a CO_2 laser to perform production rate mouth annealing operations on 5.56mm and 20mm cartridge cases as part of the small caliber ammunition modernization program (SCAMP) is examined. Analytical predictions made indicate that with a 1 KW CO_2 laser available for laboratory testing proper mouth annealing should occur in approximately 100 milliseconds for 5.56mm brass cases and in approximately 1.3 seconds for 20mm brass cases. These predictions, however, are based on the assumption that

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the laser beam average coupling coefficient to the brass case can be increased from a normal value of .03 to a value of approximately 0.4. Experimental results with a 1 KW CO_2 laser confirm that the 5.56mm and 20mm cartridge cases can be mouth annealed in approximately .100 and 1.3 seconds respectively, as predicted analytically. These times, however, are longer than that desired for SCAMP production rates and as a result, larger lasers are required. Although the laser annealing process does have some special attributes, unless they can be fully utilized and are required, replacement of present annealing techniques with the laser does not appear to be economically **practical at the present time.**

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SYMBOLS

C_p	Specific Heat at Constant Pressure
h	Height
k	Thermal Conductivity
ℓ	Thickness
P_o	Power Density
Q	Absorbed Energy
T	Temperature
T_a	Annealing Temperature
T_o	Ambient Temperature
V	Volume
X	Length Along Coordinate
Y	Length Along Coordinate
Z	Length Along Coordinate
α	Thermal Diffusivity
ξ	Defined by Equation 6
ρ	Density

INTRODUCTION

The purpose of this study is to examine the technical feasibility and economic aspects of using CO_2 laser radiation to anneal or heat treat brass and steel cartridge cases at high production rates.

The use of laser radiation to anneal selected areas on a cartridge case could provide several advantages. First, the laser beam would allow precise and accurate control of the energy deposition on the case. By adjusting the laser beam flux level and exposure time, it should be possible to introduce hardness gradients in the case that may be desirable but not possible to obtain using the present annealing and heat treating techniques. Selected zones may be annealed, e.g., the crimp area, leaving the surrounding areas unaffected. Accurate control of anneal temperatures may be accomplished by using an optical pyrometer looking at the heated zone and electrically coupled to the laser shutter.

Another area that should be examined is the possiblity of reducing electrical energy consumption. For example, the present induction coil technique used to perform the mouth anneal on 5.56mm brass cartridge cases requires an electrical input power of approximately 30 KW. If this same operation can be shown feasible with a 1 KW laser beam, it should be possible to accomplish this with an electrical input power of approximately 10 KW, thereby cutting the electrical power requirements by two-thirds. This, in itself, would not necessarily make the laser process more economical since initial capital expenditures would be higher and there is a consumption of He, N_2 and CO_2 gas with the laser. If advantages can be obtained, however, in the actual annealing process, the laser may become competitive.

The remaining portions of this report will discuss the production line requirements that must be met by a laser annealing process for both 5.56mm and 20mm cartridge cases, the results that can reasonably be expected from computations, the actual experimental results obtained with a 1 KW laser and the conclusions reached.

PRODUCTION REQUIREMENTS

5.56mm Brass Cartridge Cases

Examination of the Small Caliber Ammunition Modernization Program (SCAMP) facilities at the Twin Cities Arsenal allowed for the determination of the production line requirements that must be met by the

laser. The production goal for the SCAMP program is 1200 cases/minute and at this production rate, a chain speed of 8.7 ft/sec (104.4 in/sec) is required for the material handling equipment transporting the cartridge case blanks. The spacing between the case blanks on this chain is 5.25 inches while being processed through the drawing dies. The case blanks are normally transferred to a slower moving chain (15 in/sec) with a spacing of 3/4 inch between centers for the induction coil annealing process. Under the laser annealing concept, since each case is individually irradiated, the blanks could remain on the higher speed chain and be transferred to a rotary drum similar to the drawing presses. While in this drum, they would be rotated about their own axis at 2400 rpm and irradiated while moving from one position to another (see Figure 1). In this schematic drawing, the annealing process would occur between stations 3 and 4. The laser beam would enter the system from overhead in the center of the drum and be directed at the cartridge case by a moving mirror such that the case blank remains stationary with respect to the beam while moving from station 3 to 4. The maximum allowable time for this process is 50 milliseconds. It is not the purpose of this study to develop a laser annealer but only to outline a possible concept and determine the maximum exposure time allowable, consistent with the SCAMP production line.

20mm Brass and Steel Cartridge Cases

Present production rates for 20mm brass and steel cartridge cases is approximately 120 parts per minute. It is the desire of the Army, as part of the SCAMP program, to increase this production rate, for a given line, to approximately 600 parts/minute. If one uses basically the same concept to laser anneal the 20mm cases as was shown in Figure 1 for the 5.56mm cases, maximum exposure times for present production (120 ppm) is 500 milliseconds and for projected production rates (600 ppm) is 100 milliseconds.

LASER REQUIREMENTS

Having determined the maximum acceptable exposure times, it is then necessary to determine the power of the laser device necessary to accomplish the desired annealing. For this feasibility study, the only zone to be considered for annealing will be the case mouth. This operation is one of the final steps in the case production. In order to make these computations, a number of material parameters (Table I) and case dimensions at the mouth (Figure 2) must be specified.

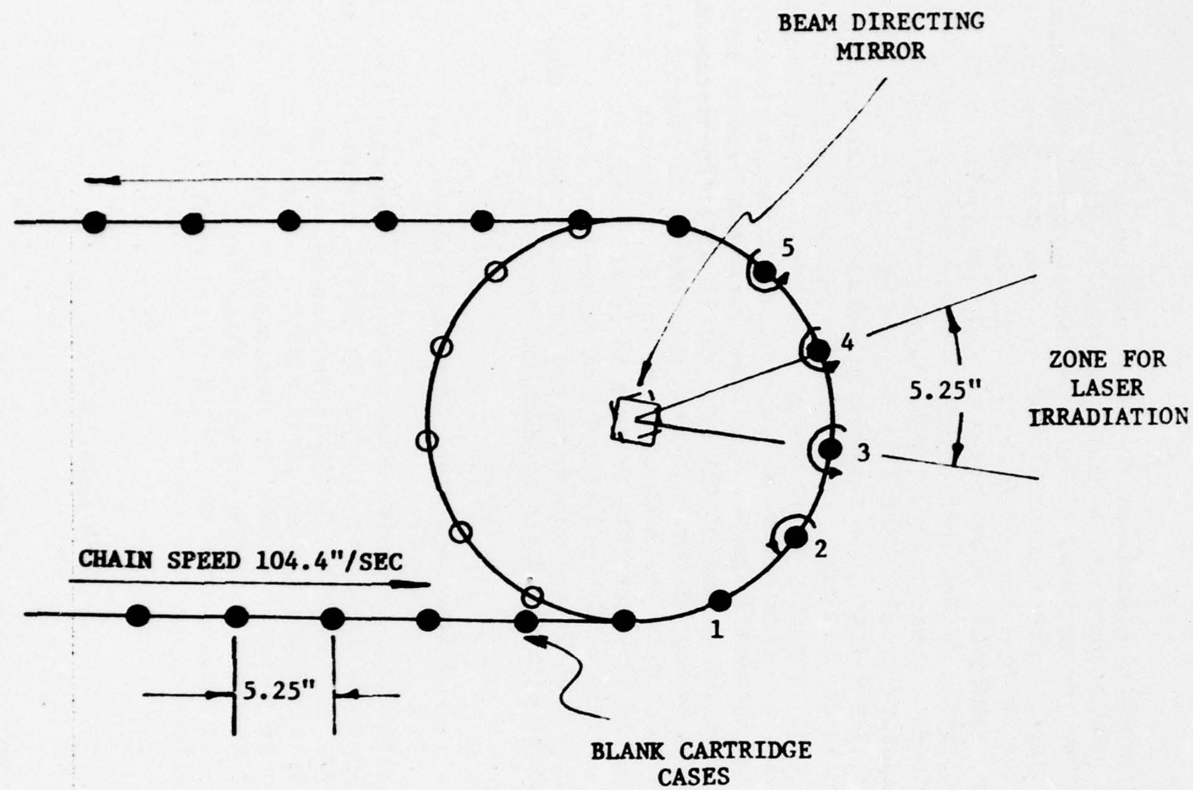


FIGURE 1. Schematic Drawing Showing Zone in Which Laser Annealing Can Occur.

TABLE I. Physical and Thermodynamic Properties.

	BRASS (70:30)	STEEL
Density (gm/cm^3)	8.53	7.82
Specific Heat (cal/gm^oC)	0.09	0.113
Thermal Conductivity ($cal/sec\ cm^oC$)	0.29	0.104
Thermal Diffusivity (cm^2/sec)	0.378	0.118
Annealing Temperature (^oC)	450.0	690.0

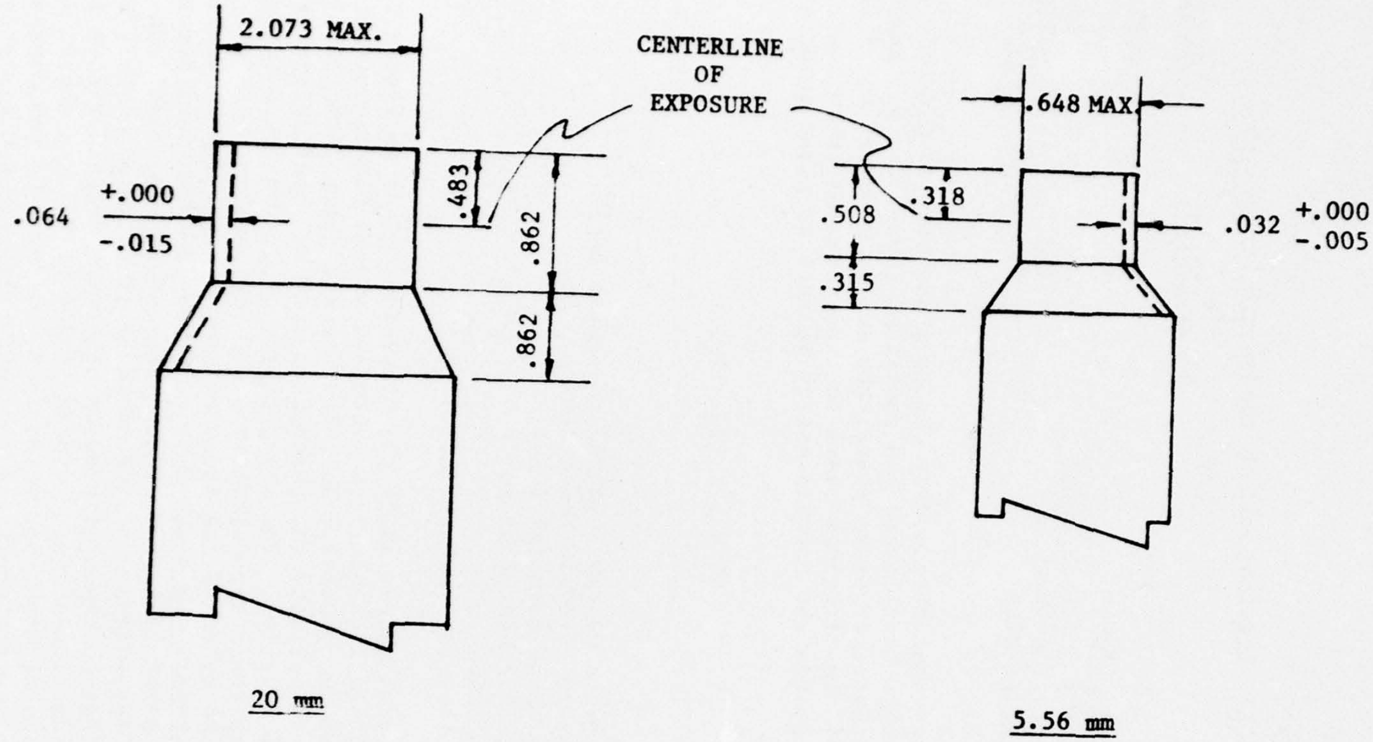
If one assumes that heat losses due to conduction to the body of the case, convective heat losses and radiation losses are all negligible during the laser exposure times, the energy required to raise just the mouth of the cartridge cases to the annealing temperature can be estimated by a straight forward energy balance as given in Equation 1.

$$Q = \rho \nu C_p (T_a - T_o) \tag{1}$$

where

Q = absorbed energy required to anneal (cal)
ρ = density of 70:30 brass (gm/cm^3)
ν = volume of material (cm^3)
C_p = specific heat (cal/gm^oC)
T_a = annealing Temperature (^oC)
T_o = ambient Temperature (22^oC)

For 5.56mm brass cases, using the dimensions given in Figure 2 and the properties given in Table I, an absorbed energy requirement of 10.2 cal (42.6 joules) is computed. To calculate the laser power required, it is necessary to estimate the absorption coupling coefficient between the beam and the material. The absorptivity of virgin brass to CO_2 radiation is very low - approximately 0.03. This value, however, can be increased by an order of magnitude or more by applying absorptive coatings to the brass. Previous work conducted at Frankford Arsenal as well as work by other authors indicated that absorption coefficient from 0.2 to 0.6 (depending upon the incident flux) were possible with metal surfaces that had been painted or otherwise treated with a thin absorptive film and therefore, a nominal value of 0.4 was chosen in order to estimate the laser power required. It must be remembered, however, that an absorption coefficient of approximately 0.4 can only be anticipated for a surface that is properly treated with a highly laser absorbing film. With an assumed absorption coupling of 40% between the beam and 5.56mm case, the total output energy required from the laser is 106.4 joules.



Note: All dimensions are in centimeters.

FIGURE 2. 20 mm and 5.56 mm Cartridge Case Dimensions.

From the previous determination of production requirements, it was seen that a maximum annealing time allowable for the 5.56mm cases was 0.050 seconds; hence the laser output power required is 106.4 j/0.050 sec or 2130 watts. In our experimental work, however, only a 1 KW laser is available. It would, therefore, be expected that exposure times on the order of 100 milliseconds will be required to achieve proper annealing.

Although heat losses have been neglected, conduction of energy through the wall of the cartridge case is quite rapid as is shown by the discussion below.

It will be assumed that the mouth area of a rotating 5.56mm cartridge case is irradiated by a 1 KW CO_2 laser with an average power density in the beam of 4 KW/cm^2. At this flux level, the diameter of the beam from a 1 KW laser is approximately .56cm (or slightly larger than the height of the 5.56mm mouth). The circumference of the case mouth is 1.994 cm and, therefore, at any given instant 28.3% of the case is being irradiated. Since the case is rotating (2400 rpm), the assumption will be made that the average power density over the entire mouth area is .28 (4 KW/cm^2) or 1.120 KW/cm^2 = 1120j/sec cm^2 = 271 cal/sec cm^2. It has also been previously assumed that 40% of the beam energy can be absorbed by the case. Hence, the energy density per unit time absorbed is 108.5 cal/sec cm^2.

The problem can now be considered as a sheet or slab of finite thickness being irradiated on one surface. It will also be assumed that the opposite surface is insulated. That is, heat losses on that side are negligible. In order to model this problem, it will be assumed that the slab is infinite in the X and Y direction and the laser irradiation is uniform over the entire surface Z = 0. The thickness of the slab will be ℓ, and the average absorbed power density P_o will be assumed to be constant. It will also be assumed that all the radiation is absorbed in a narrow layer at Z = 0. Figure 3 illustrates the problem.

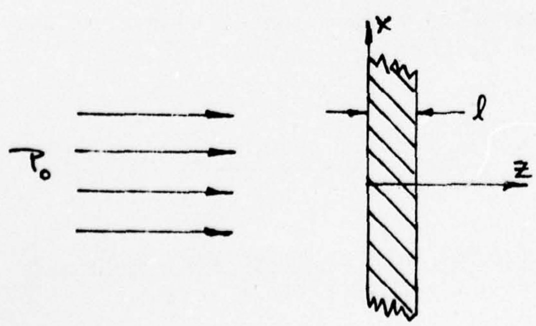


FIGURE 3. Schematic Illustration of Laser Irradiation of Thin Plate.

The heat transfer equation and boundary conditions that must be satisfied are:

$$\frac{\delta^2 T}{\delta Z^2} - \frac{1}{\alpha}\frac{\delta T}{\delta Z} = 0 \qquad (2)$$

$$-k \left.\frac{\delta T}{\delta Z}\right)_{Z\,=\,0} = P_o \qquad (3)$$

$$-k \left.\frac{\delta T}{\delta Z}\right)_{Z\,=\,\ell} = 0 \qquad (4)$$

The solution to this partial differential equation and boundary conditions has been computed by a number of authors [2,3] and is given as

$$T(Z,t) = \frac{P_o \ell}{k}\left\{\frac{\alpha t}{\ell^2} + \xi\right\} \qquad (5)$$

where

$$\xi = \frac{3(\ell - Z)^2 - \ell^2}{6\ell^2} - \frac{2}{\pi^2}\sum_{n=1}^{\infty}\frac{(-1)^n}{n^2}e^{-\alpha n^2 \pi t/\ell^2}\cos\left[\frac{n\pi(\ell - Z)}{\ell}\right] \qquad (6)$$

The temperature distribution given by Equation (5) shows a linear increase with time $\{P_o \alpha t/k\ell\}$ plus a correction term (ξ) that is a function of position and time. This correction term is plotted in both References 2 and 3 and is duplicated in Figure 4 for convenience. It will be noticed in Figure 4 that the limiting values are reached very rapidly and are nearly realized by the time $\alpha t/\ell^2 = 1$. Hence, from Figure 4 for values of $\alpha t/\ell^2 >> 1$ when $Z = 0$ the correction term is approximately +.33 and when $Z = \ell$ the correction term is approximately -0.17.

If we examine the temperatures as a function of time from Equation (5) for the special case of $Z = 0$, then

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[2]Carslaw, H. S., Jaeger, J. D.; "Conduction of Heat in Solids;" Oxford University Press; 1959; pp. 113.

[3]Schriempf, J. T., "Response of Materials to Laser Radiation: A Short Course;" NRL Report 7728; July 10, 1974; pp. 33.

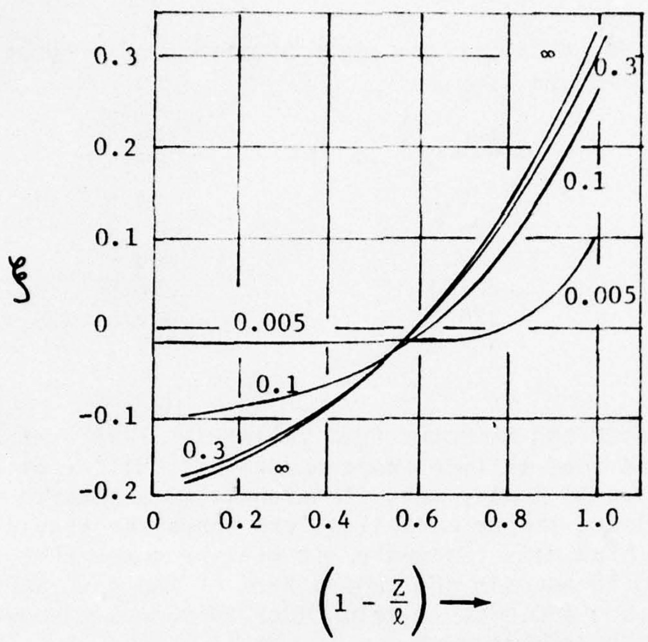

FIGURE 4. Correction Term ξ as a Function of $(1 - Z/\ell)$ for Several Values of $\alpha t/\ell^2$.

$$T(0,t) = \frac{P_o \ell}{k} \left\{ \frac{\alpha t}{\ell^2} + .33 \right\} \tag{7}$$

and for the case $Z = \ell$

$$T(\ell,t) = \frac{P_o \ell}{k} \left\{ \frac{\alpha t}{\ell^2} - .17 \right\} \tag{8}$$

The difference between the front and the back surface temperature at any time can be expressed

$$T(0,t) - T(\ell,t) = 0.5 \ \frac{P_o \ell}{k} \tag{9}$$

The above Equations (7), (8) and (9) are only valid, however, when $\alpha t/\ell^2 >> 1$. For the conditions of a 5.56mm brass case $\alpha = 0.378$ cm^2/sec, $\ell^2 = (0.0305 \text{ cm})^2 = 9.29 \times 10^{-4}$ cm^2 and if an exposure time of 0.01 seconds is assumed the $\alpha t/\ell^2 = 4.07$. This obviously satisfies the criterion to make Equations (7) through (9) valid; and as the exposure times become longer, $\alpha t/\ell^2$ becomes even larger. Table II gives the change in front $(Z = 0)$ and the rear surface $(Z = \ell)$ temperatures from ambient conditions.

TABLE II. 5.56mm Brass Cartridge Case Temperature as a Function of Laser Exposure Time.

t (sec)	$\Delta T_{Z=0}$ (°C)	$\Delta T_{Z=\ell}$ (°C)
0.01	50.2	44.5
0.02	96.6	90.9
0.04	189.5	183.8
0.06	282.3	276.6
0.08	375.2	369.5
0.10	468.0	462.3

A number of facts can be noted from Table II. First, at any given time, the front and rear surface temperatures only differ by approximately 6°C. This would imply, that if hardness measurements on the front surface indicate proper annealing, the annealing should be uniform through the thickness. Secondly, it will be noted that at an exposure time of 0.10 seconds the temperature of the case mouth should reach 468.01 + 22.0 = 490.0°C. A value that is somewhat above the desired 450°C annealing temperature.

From the above computations, it would be expected that proper mouth annealing of the 5.56mm brass cartridge case should occur with a laser exposure of approximately 0.100 seconds; assuming the case mouth is exposed by a 1 KW laser at a power density 4 KW/cm^2 and beam coupling coefficient of 0.40 can be achieved.

Similar computations can be made for 20mm brass and steel cartridge cases. For example, the volume of material to be annealed in the 20mm cases, that is comparable to 5.56mm cases, can be computed as 0.344cm^3.

The absorbed energy required to raise this volume of material to the proper annealing temperature can be computed from Equation (1). For the brass 20mm cases this energy is 471.8j. If it is again assumed that a 40% beam coupling coefficient is achievable, then the laser beam energy becomes 1180.0j. Since only a 1 KW (1000j/sec) laser is available for experimental work, this requires an exposure time of 1.18 seconds.

The next question to be answered is what will the front and rear surface temperature be after an exposure of 1.18 seconds. Since $\alpha t/\ell^2$ = 9.37 when t = 0.1 sec, Equation (7) through (9) remain valid for the exposure of interest and front (Z = 0) and back (Z = ℓ) surface temperature changes from ambient can be computed. Since the mouth of the 20mm cartridge cases are so much larger than the 5.56mm cases and it is

desired to irradiate this area as uniformly as possible, a power density of 1 KW/cm^2 will be assumed. Following the same argument as before, it appears that the beam diameter only covers approximately 17.4% at any given instant. Therefore, the average power density over the entire case mouth is 174 w/cm^2. Since a 40% coupling coefficient has previously been assumed, this implies that the absorbed energy density per unit time is 16.7 $cal/sec\text{-}cm^2$. Substituting this value into Equations (7) and (8), Table III can be generated for 20mm brass cases.

TABLE III. 20mm Brass Cartridge Case Temperature as a Function of Laser Exposure Time.

t (sec)	ΔT (°C) $Z=0$	ΔT (°C) $Z=\ell$
.2	69.8	68.0
.4	138.4	136.5
.6	207.0	205.1
.8	275.5	273.7
1.0	344.1	342.3
1.2	412.7	410.9
1.4	481.3	479.5

From the above computations it would be expected that proper annealing of the 20mm brass cases should be achieved with a 1 KW laser in approximately 1.2 - 1.4 seconds. This assumes a beam power density of 1 KW/cm^2 and a coupling coefficient of 0.40.

It is clear from the above results that annealing 20mm brass cartridge cases at the required production rate for the SCAMP program (600 ppm) will require a laser of approximately 1180.0j/0.10 sec = 12 KW. Or, looking at it another way, if the power density is increased by a factor of 12, for the same beam area, the annealing time can be reduced by approximately the same factor.

EXPERIMENTAL RESULTS

Prior to conducting any experimental tests on the cartridge cases, it was necessary to find a coating that would substantially increase the absorption of the beam energy into the brass. As was previously stated, the absorption coefficient of the bare brass is approximately 0.03 and our computations were based on an assumed absorption coeffic-

cient of 0.4. A number of coatings to increase the absorptivity were examined and included such things as films of carbon, silicone, sodium silicate, nickel black, as well as drawing compounds and lubricants that are presently being used in the production of 5.56mm and 20mm cases (e.g., Zephyr-oid, Potters Kly, Accrus and Macro Dri 3V).

A literature survey was also made of coatings that would not only couple the beam to the cartridge case, but limit at least for a time, the temperature to which the surface would rise before the coating completely melted or vaporized. This survey (Table IV) revealed a number of coating materials whose melting points or boiling points were in a range suitable for use with the brass cartridge cases but they were discarded because of economic or safety considerations. Although it is realized that the cost of these materials, in many cases, could be substantially reduced if purchased in quantity, they were not considered reasonable to demonstrate the feasibility of the laser heat treating concept.

When the drawing compounds and lubricants were placed on the 5.56mm cartridge cases and exposed to the laser, little or no temperature rise occurred, compared to the carbon, nickel black, silicone and silicate films. Since maximum coupling was desired, the drawing compounds and lubricants were also rejected. The only materials that appear, at the present time, to couple the beam energy strongly enough are silicone, silicate, nickel black and carbon films. Unfortunately, the first two of the materials may present problems if used during an intermediate annealing process. That is, if further drawing operations are to be done. When these materials are exposed to laser radiation, they break down and form silicon oxides that may prove abrasive to the dies.

The nickel black is an electrolytic process that produces a very thin coating that strongly couples the laser energy. The drawback of this process is that it requires additional electrical power and would be somewhat difficult to remove. If having black cartridge cases is not undesireable, such that the coating does not have to be removed, this may be a promising way to go. Unfortunately, black cartridge cases presently signify a dummy round.

The prime candidate, as an absorbing material, is the carbon film. This film is basically a formulation of india ink, a wetting agent (MICRO) and a rapid drying agent (alcohol). This system is water soluble and can be rapidly removed with warm water. After exposure to the laser, however, there is a tendency for the carbon film to bake on and it may require a light brushing in addition to the warm water rinse to remove. Although the prime candidate for an absorbing layer is the carbon film, experimental testing of the brass cases also included the silicone, nickel black and silicate films. In addition to these, a phosphate coating was used on the steel cases.

TABLE IV. Melting Points and Boiling Points of Several Compounds.

Melting Points

Temp °C	H. Book* I.D. No.	Name	Remarks	Cost
422	a1311	1, 5, dinitro Anthraquinone	Sublimes	
450	b1103	Benzene Sulfonic Acid, Sodium Salt	Decomposes	$8.50/1kg
	e36	Ellagic Acid, Dihydrate	Decomposes without melting	$15.00/10g
470	i40	Indanthrene	Decomposes	$8.00/10g
490	d109	Dibenzanthrone	Decomposes	$8.00/100g

Boiling Points

Temp °C	H. Book* I.D. No.	Name	Remarks	Cost
425	b1957	9, 10 Benzophenanthrene (Triphenylene)		$19.50/5g
430	a1286	1, 2 Dihydroxy (Alizarin) Anthraquinoline	(Sublimes)	$7.00/10g
431	m300	Tetraphenyl Methane	(Sublimes)	$24.00/5g
431	01	Octacosane (28C)		$9.00/25g
435	b181	1, 2 Benzanthracene	(Sublimes) C#	$17.50/5g
441	m502	Nonacosane (29C)		$34.00/10g
442	033	Octadecanoic Acid, Methyl Ester (Methyl Stearate)		$6.50/kg
445	m175	1, 8 DiNitronaphthalene	(Decomposes)	$9.00/5g
446	n387	Naphtho (2', 3': 5, 6) Quinoline (B - Anthro-quinoline)		$12.00/10g
448	c313	Chrysens (1, 2 - Benzo Phenanthrene		$10.00/100g
450	t699	Triacontane (30C)		$45.00/10g
452	b2208	2, 2 Binaphthyl	(Sublimes)	$10.50/5g
458	h61	Hentriacontane (31C)		
459	b982	1, 3, 5 Triphenylbenzene		$7.00/100g
467	d323	Dotriacontane (Dicetyl) 32C		$7.50/25g
471	a858	di-2-Naphthyl Amine		
480	b1228	11, 12 BenzoFluoranthene		
518	P908	Picene (DiBenzo (ai) Penanthrene)		$47.00/100mg
546	a132	4, 4 Diaminostigmasterol	(Sublimes)	

*Handbook of Chemistry & Physics 52 No. Ed, 1971-72, Chemical Rubber Publishing Company, Cleveland, Ohio.

#C = Carcinogenic

Irradiation of the 5.56mm and 20mm cartridge cases was accomplished by rotating them at a speed of 2400 rpm, using a voltage controlled DC motor, at a point where the focused beam power density was 4 KW/cm^2 and 1 KW/cm^2 respectively. A magnetic pick-up was used to sense each rotation of the cartridge case and this signal was fed into a special designed electronic counter that controlled the laser exposure. The counter allowed the laser operator to pre-set a fixed number of revolutions of the cartridge case. When the case was rotating at a fixed speed and the start button pushed, the counter would turn on the laser, count the number of revolutions desired and then turn the laser off. Hence, if the counter was set at 2, 4, 6, or 8 revolutions, exposure times (at 2400 rpm) of 50, 100, 150, and 200 milliseconds were obtained. Figure 5 schematically illustrates the laboratory set up.

The experimental results obtained by laser annealing 5.56mm brass cartridge cases is shown in Table V. The hardness after exposure values are given by first indicating the sample number and then listing the four hardness readings around the case in parenthesis. Four samples 1-4 were chosen at random from the cases supplied to serve as control specimens of the unannealed cartridge cases. It will be noticed that every one of these samples has one tested point where the hardness is much lower than the other three readings. This would indicate that the hardness of the cases prior to annealing are not as uniform as desired and would probably provide an explanation for some of the variation of the four hardness readings in a given cartridge case after laser annealing. Samples 45-48 were exposed as received and it is clear from the results that little or no annealing occurs when absorbing surface coatings are not applied. Samples 5-20 involved the use of a carbon ink absorbing coating and it appears, from the results, that a 100 millisecond exposure will achieve annealing conditions very closely to those desired (85-115 Vickers). This exposure is the same as predicted in the laser requirements section for proper annealing with an exposure of 50 milliseconds little or no annealing occurs and when the exposure time is 150 milliseconds, the frequency of readings that are lower than desired increases. Sample 14 was not measured because of defects (slight grooves) in the case mouth. At 200 milliseconds, the two cases tested were severely melted and the last two cases at this exposure time were not run.

When the nickel black, silicone and silicate films were used as absorbing coatings, the same basic results are noted. In all cases, however, the nickel black and silicate coatings provided a greater degree of annealing than the ink (carbon) or silicone for the same exposure time. When the exposure time is 100 milliseconds, the nickel black and silicate provide significant annealing and give values that are on the lower side of the acceptable range (85-115 Vickers). Sample 32 was not measured because of surface marks on the case mouth.

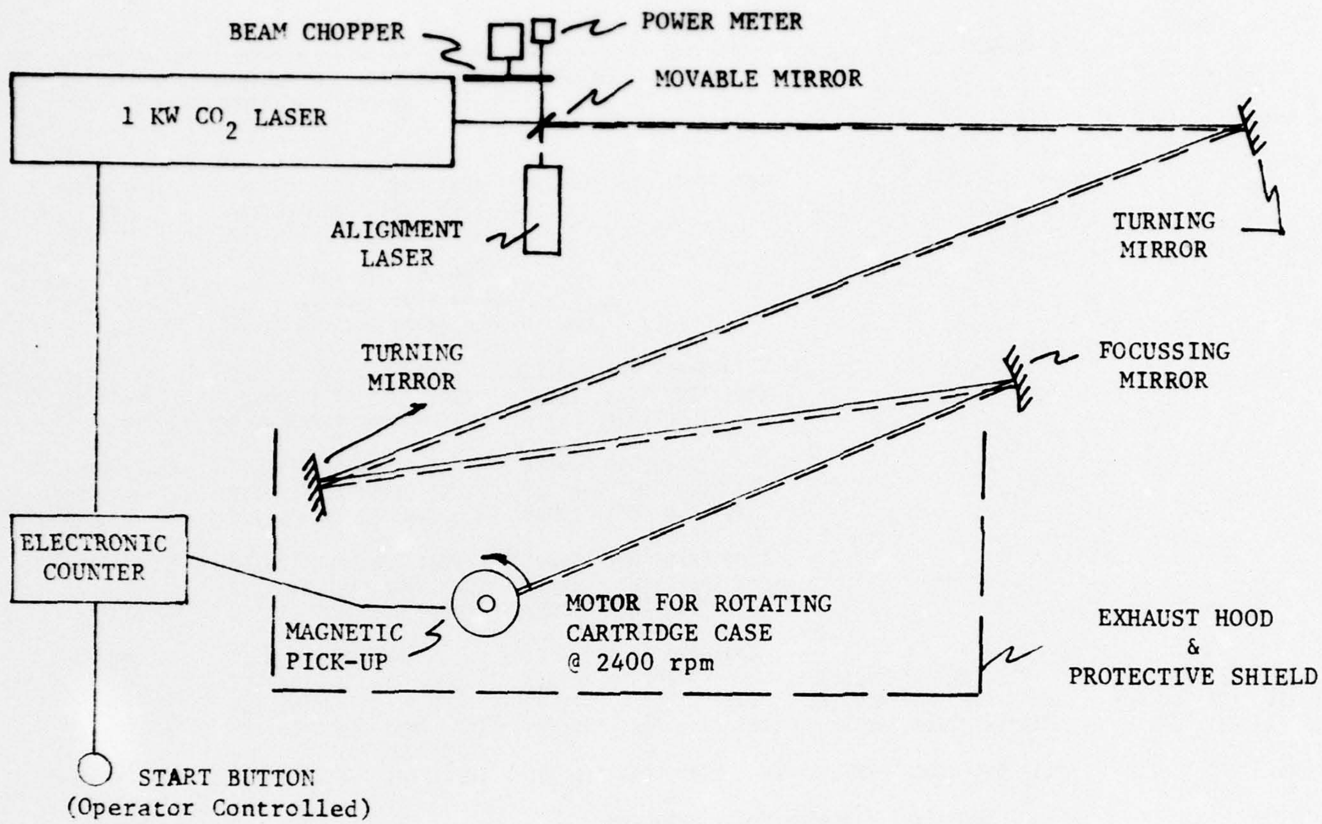

FIGURE 5. Schematic Drawing of Test Facility.

TABLE V. Hardness Measurements for 5.56mm Brass Cartridge Cases.

Exposure Time (See)	Surface Coating	Hardness After Exposure (Vickers)			
Control	(Not Exposed)	1(157, 196, 193, 193)	2(191, 193, 168, 193)	3(188, 201, 164, 196)	4(193, 168, 196, 146)
.050	Ink	5(140, 121, 143, 183)	6(191, 179, 191, 191)	7(143, 201, 196, 193)	8(157, 181, 191, 193)
.100	Ink	9(110, 77, 101, 110)	10(136, 111, 79, 96)	11(116, 98, 83, 116)	12(109, 131, 92, 83)
.150	Ink	13(100, 72, 90, 115)	14(not measured)	15(74, 78, 78, 71)	16(74, 116, 113, 75)
.200	Ink	17 & 18(damaged)	19 & 20(not exposed)		
	Nickel Black	21(78, 102, 181, 130)	22(87, 109, 188, 186)		
.050	Silicone	23(166, 191, 188, 191)	24(177, 191, 198, 203)		
	Silicate	25(92, 98, 183, 188)	26(93, 188, 122, 102)		
	Nickel Black	27(70, 87, 82, 68)	28(80, 100, 84, 83)		
.100	Silicone	29(198, 77, 181, 150)	30(146, 166, 175, 101)		
	Silicate	31(85, 74, 83, 80)	32(not measured)		
	NB	33(surface damaged)	34(not measured)		
.150	Silicone	35(81, 106, 126, 108)	36(77, 110, 111, 104)		
	Silicate	37(72, 81, 68, 68)	38(surface damaged)		
	NB	Tests not run because of damage			
.200	Silicone	to cartridge cases			
	Silicate	at .150 seconds.			
.100	Exposed	48(191, 160, 155, 196)			
.150	as	47(124, 193, 188, 201)			
.200	Received	45(155, 193, 193, 188)	46(186, 203, 196, 191)		

NOTE:

1. All exposures made at 4 KW/cm^2.
2. Rotational speed for all cartridge cases was 2400 rpm.
3. Hardness tests were made at 90 degree intervals in the case neck 1.620" from the head.

These defects were not due to the laser annealing process, but were scored during a drawing process. At 150 milliseconds the silicone coating is providing proper annealing. The nickel black and silicate, however, are causing the surface to be melted and significant softening of the case mouth. The samples set aside for the 200 millisecond test were not run because of the damage occurring to the cases at 150 milliseconds. The averaged data from Table V is plotted in Figure 6.

In an attempt to examine the microstructure of the laser annealed 5.56mm cartridge cases, several photomicrographs were made of the annealed cases as well as several control specimens. In Figures 7 and 8, typical photomicrographs of control specimen #1 (Table V) and annealed specimen #12 (Table V) are shown. These specimens were sectioned to form an annular ring at a point 0.318cm from the case mouth and examined under 300X magnification. Although these photographs do not show the total ring, it is clear from the curvature seen in the pictures which is the interior and exterior of the case.

A very fine grain structure will be noticed in control specimen #1 which is typical of work hardened materials. The annealed specimen #12, on the other hand, has very large well defined grains indicating a great deal of recrystallization and is typical of a material that has been annealed. It will also be noticed that the large grain structure is uniform across the thickness of the case. This was expected since the computations indicated a $6^{o}C$ temperature differential between the outside (exposed) and inside surface.

The laser annealing that was achieved with the 20mm brass and steel cartridge cases is shown in Tables VI and VII. All of these exposures were made at a power density of 1 KW/cm^2. Although a larger statistical data base would have been desirable, this was not possible with the funds available. The average hardness readings from Table VI are plotted in Figure 9 where it is clear that superior coupling of the beam energy is achieved with the nickel black coating. This result is in agreement with the data taken for the 5.56mm brass cases and illustrated in Figure 6. The proper range of hardness readings is achieved for the nickel black coatings when the exposure times are between 1.0 and 1.5 seconds and is in good agreement with the exposure times previously predicted from calculations. With the ink (carbon coatings), however, exposure times from 1.5 to 2.0 seconds are required for proper annealing. This difference is probably due to the coupling coefficient being somewhat lower than estimated.

Based on the case surface temperature as a function of exposure time (Table III) and the average hardness values versus exposure time shown in Figure 9, it appears that recrystallization occurs very rapidly as the annealing temperature is reached. As the exposure times become

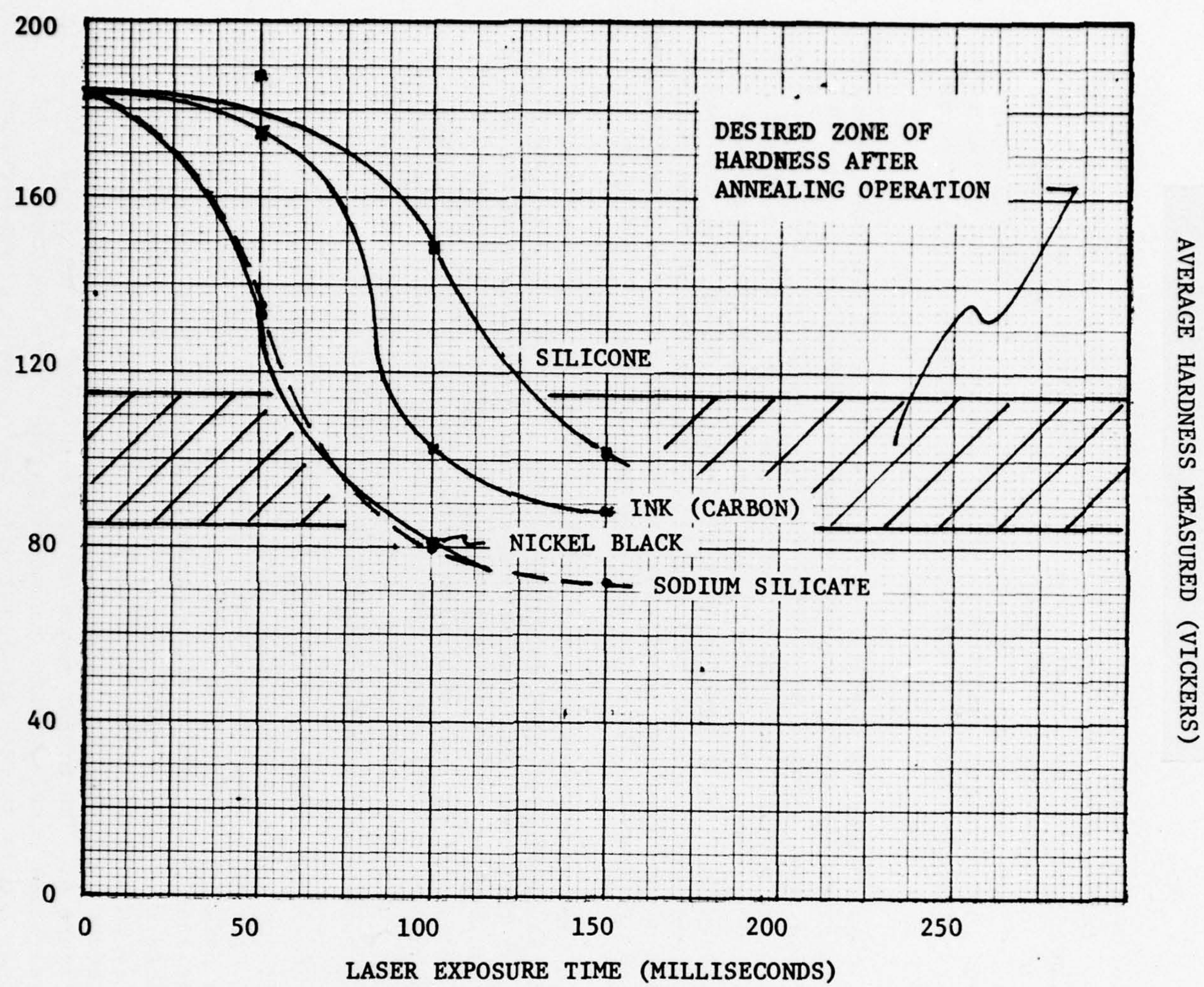

FIGURE 6. Laser Mouth Anneal of 5.56 mm Brass Cartridge Cases.

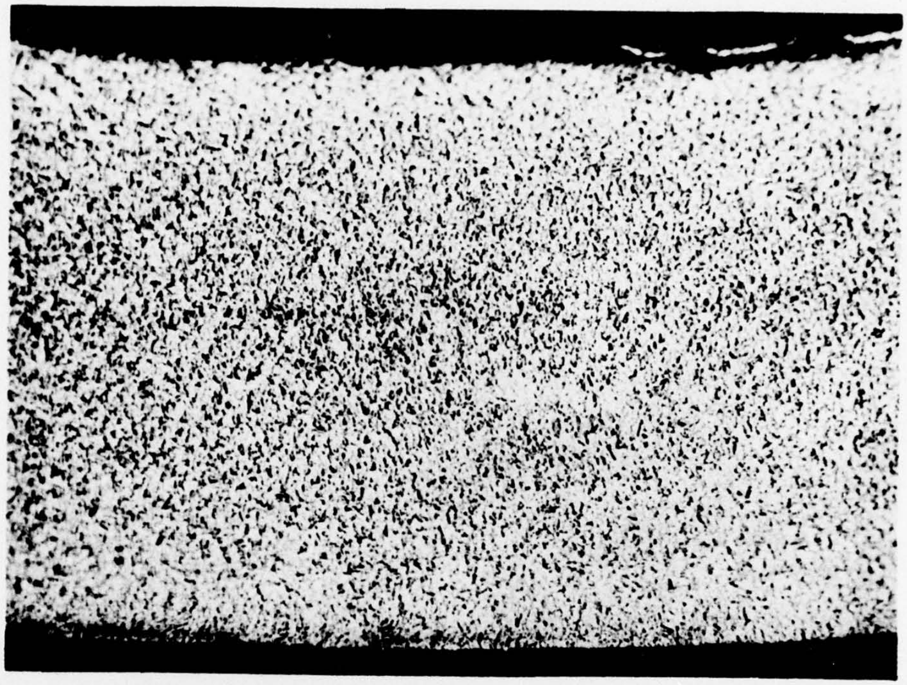

FIGURE 7. Photomicrograph of Work Hardened 5.56mm Brass Cartridge Case (Specimen #11). Case was sectioned at a point 0.318cm from the Mouth of the Case to form an Annular Ring. Magnification of Photograph is approximately 300X.

FIGURE 8. Photomicrograph of Laser Annealed 5.56mm Brass Cartridge Case (Specimen #12). Case was sectioned at a point 0.318cm from the Mouth of the Case to form an Annular Ring. Magnification of Photograph is approximately 300X.

TABLE VI. Hardness Measurements of 20mm Brass Cartridge Cases.

20mm Brass Cartridge Cases

Exposure Time (Sec)	Surface Coating	Hardness after Exposure (Vickers)	
Control	(Not Exposed)	2(177, 177, 179, 179)	
0.5	Ink	7(177, 186, 177, 177)	
1.0	Ink	15(159, 162, 170, 166)	16(172, 177, 168, 164)
1.5	Ink	18(96, 99, 131, 116)	19(99, 99, 105, 121)
2.0	Ink	23(82, 82, 83, 80)	24(85, 83, 88, 87)
2.5	Ink	25(88, 83, 72, 79)	26(66, 71, 73, 77)
1.0	Nickel Black	29(164, 166, 128, 123)	30(99, 101, 101, 99)
1.5	Nickel Black	33(77, 71, 71, 75)	34(96, 94, 91, 98)
2.0	Nickel Black	37(66, 61, 64, 64)	38(76, 72, 64, 72)
2.5	Nickel Black	41(64, 62, 63, 62)	42(60, 61, 67, 71)

TABLE VII. Hardness Measurements for 20mm Steel Cartridge Cases.

20mm Steel Cartridge Cases

Exposure Time (Sec)	Surface Coating	Hardness after Exposure (Vickers)	
Control	(Not Exposed)	1(230, 230, 227, 243)	
1.0	Ink	10(254, 224, 218, 233)	
1.5	Ink	53(170, 172, 162, 162)	54(172, 181, 172, 177)
2.0	Ink	57(155, 160, 162, 157)	58(170, 166, 162, 160)
2.5	Ink	61(160, 155, 160, 164)	62(155, 150, 164, 168)
3.0	Ink	65(160, 160, 157, 166)	66(175, 172, 164, 172)
1.5	Nickel Black	69(191, 168, 172, 212)	
2.0	Nickel Black	71(175, 170, 157, 160)	
2.5	Nickel Black	73(160, 164, 159, 160)	
3.0	Nickel Black	75(164, 164, 164, 160)	
1.5	Phosphate	77(203, 196, 186, 193)	
2.0	Phosphate	79(155, 157, 168, 164)	
2.5	Phosphate	81(172, 177, 162, 162)	
3.0	Phosphate	83(168, 168, 164, 160)	

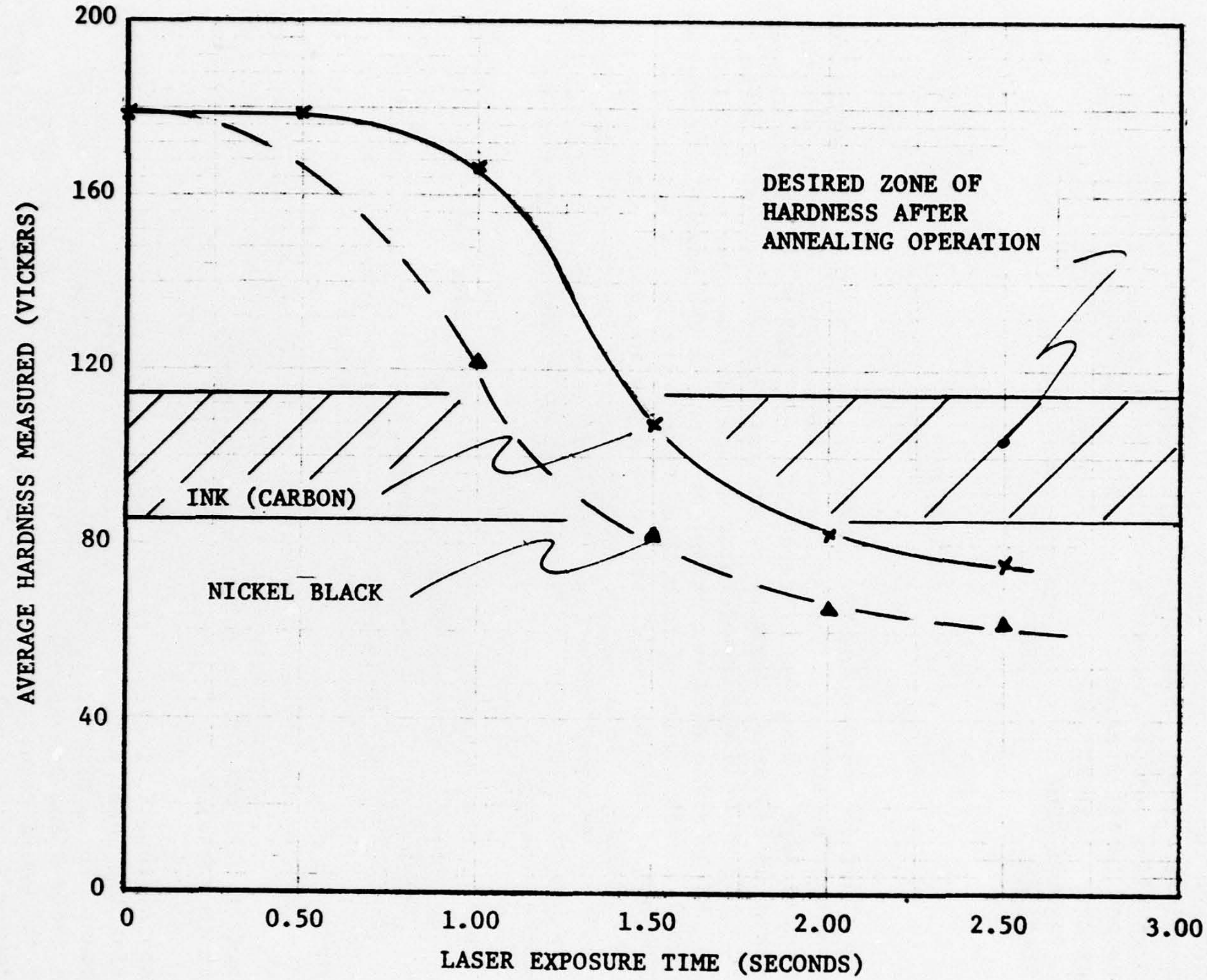

FIGURE 9. Laser Mouth Anneal of 20 mm Brass Cartridge Cases.

longer and the temperature continues to increase, the change in hardness values quickly levels off. This rapid change in hardness and then leveling out is also apparent in the data taken for the 20mm steel cases and is illustrated in Figure 10. It will also be noted for the steel cases that the ink coating proved to be the most effective in coupling the beam energy. This conclusion, however, is based on very limited data.

CONCLUSIONS

In order to achieve desired annealing temperatures, an absorptive coating must be applied. The strongest beam energy coupling, for the brass cartridge cases, was achieved when a nickel black or sodium silicate coating was used. Because of several disadvantages with these coatings (such as a permanent color change, in the case of the nickel black, and possible silicone oxide residues, in the case of the sodium silicate) a carbon coating formulated from india ink, a wetting agent (MICRO) and alcohol to cause rapid drying was found to be the best all around candidate. This coating could be easily applied and rapidly removed with warm water and a light brushing after being irradiated. The ink coating was also found to be the most effective coupler for the 20mm steel cases.

Based on the experimental data, it is quite clear that a 1 KW CO_2 laser can anneal 5.56mm and 20mm cartridge cases. It does not, however, appear possible within the allowed exposure times required for desired production rates. By increasing the laser output power the desired production rates could be met for the mouth anneal. In the case of the 5.56mm brass cartridge cases it appears that a 2.5 KW laser would be able to perform the annealing operation in the desired 50 milliseconds. In the case of both the steel and brass 20mm cartridge cases, a desired production rate of 600 ppm requires approximately a 12-15 KW laser for the mouth anneal.

Any system, in addition to the laser, would require a method for rotating the cases and a mirror system for positioning and focusing the beam. This, of course, adds to the total system cost. Present laser costs alone are approximately $50.00 per watt of beam output power and would require a capital expenditure greater than the present gas jet or induction coil annealers and associated equipment.

The laser system, on the other hand, does eliminate the need to change the cartridge case spacing on the transporting chain and does provide the advantage of selective annealing if desired. Unless these advantages can be shown to be necessary, however, for the proper production of the cartridge cases, it does not, at the present time, appear economically practical to use a laser for annealing.

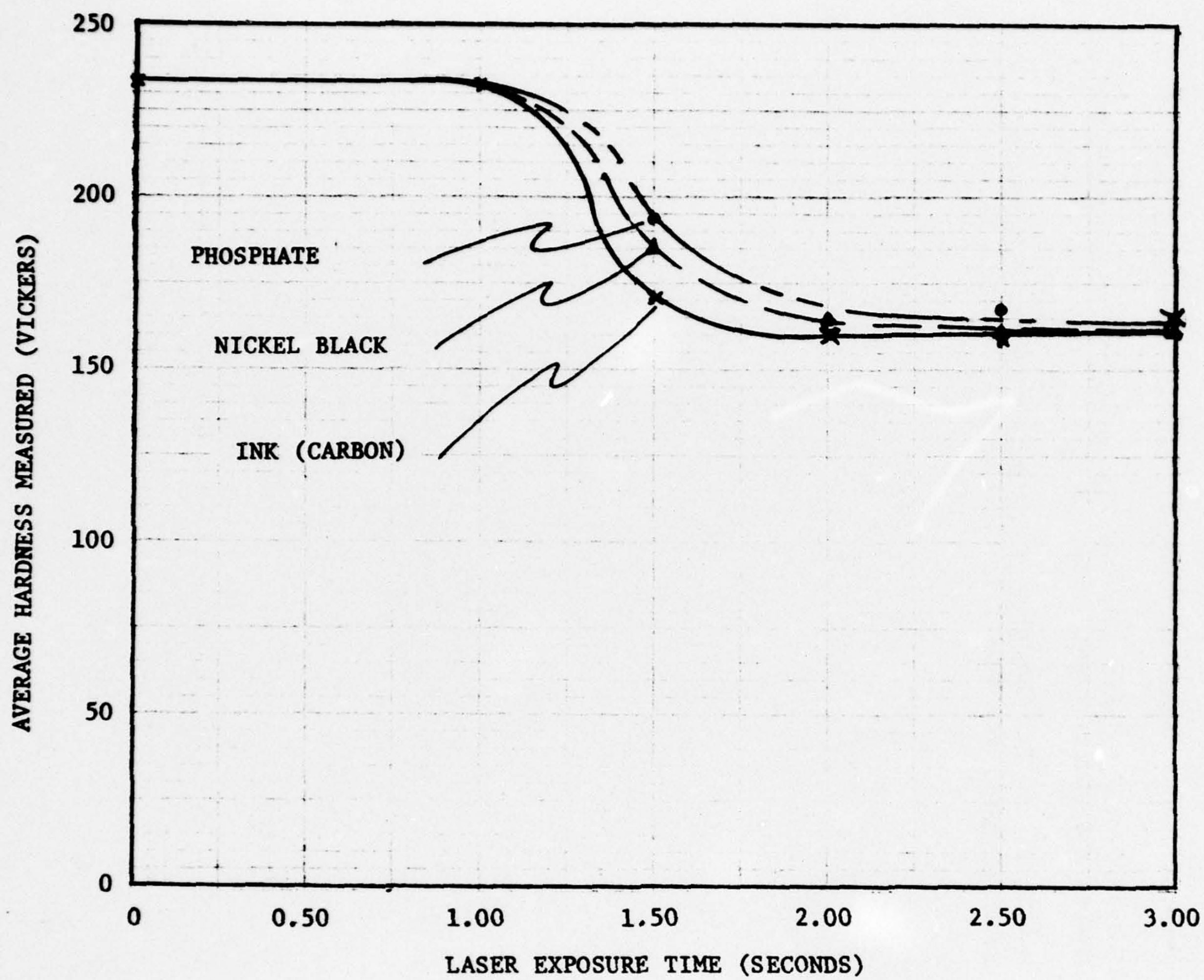

FIGURE 10. Laser Mouth Anneal of 20 mm Steel Cartridge Cases.

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